SENSORY AID FOR THE BLIND

Lawrence Cranberg

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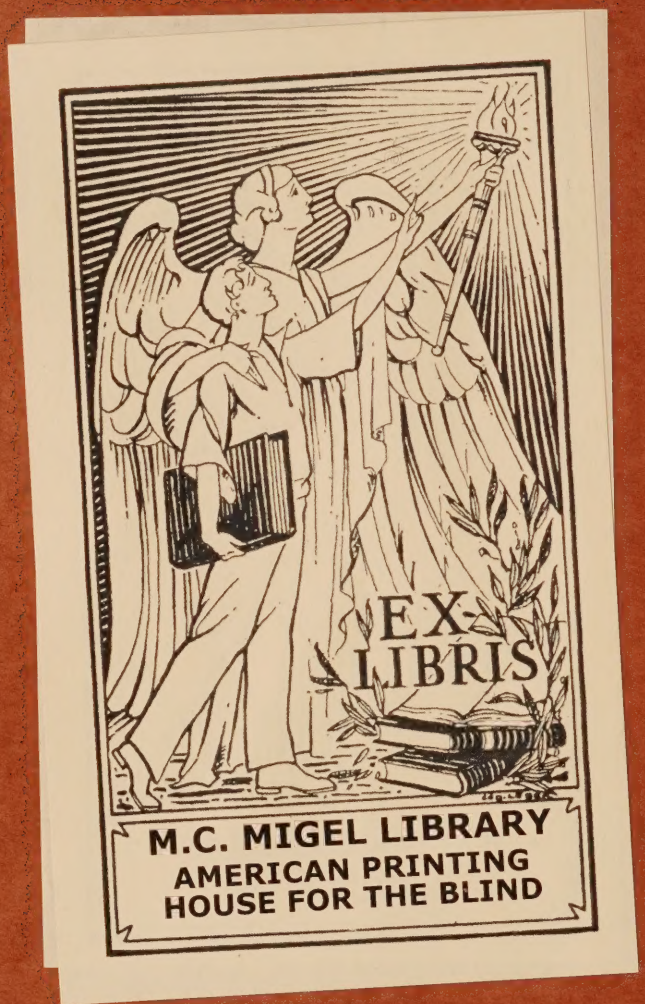
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SENSORY

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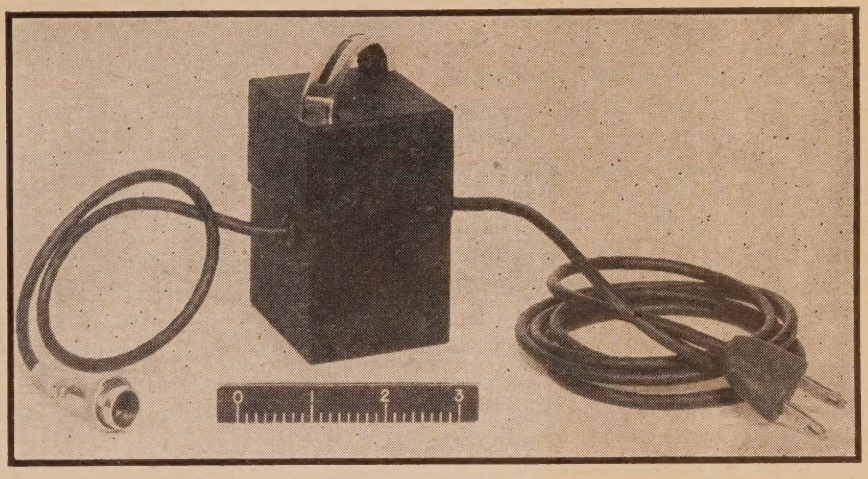
Sensory aid developed by Signal Corps Engineering Laboratories. The air-conduction headphone is shown at the right. The complete unit weighs about nine pounds



Miniature battery charger for the sensory aid unit. This is operated from ordinary 115 v a-c mains

THE NEED for a means which would indicate to a blind person the presence of obstacles in his path, or irregularities in the ground surface such as steps and holes, and the distance to them, has been long and keenly felt. Everyone is familiar to some extent with the role played in this connection by the Seeing Eye dog. However, numerous factors limit the proportion of sightless people who can use the dog, and indicate the need for a device which might perform at least some of the same functions.

Very little, if any, work aimed at the development of such a device had been done prior to the war. However, World War II, with its blinded veterans and its dramatic demonstration of the powers of the electronic art, has provided real impetus toward such a development. Activity was initiated at the Signal Corps Engineering Laboratories at Bradley Beach, New Jersey, in April 1945, at the request of the Surgeon General. Earlier activity was started under OSRD auspices.

This article in no sense reports a finished work. It is intended as an interim report only, to record the results of progress at this laboratory to date and to stimulate ideas for other methods of attack on this humanely important problem.

Specific performance requirements for a practical device agreeable to all are not easily defined. Tentatively, the following objectives have been set up: (1) to detect steps up and steps down; (2) to provide information sufficient to enable a person to follow a straight line such as that indicated by curbing or a wall; (3) to detect objects between 3 and 6 feet away with which a person may collide; (4) to provide information sufficient to enable a person to get a rough plan-position picture of his environment; (5) to accomplish the above with reasonable speed and reliability with a minimum of training and equipment, and a minimum of interference with the user's hearing.

It would appear in principle that a ranging device of suitable resolution in azimuth and elevation—in effect on extended cane—would provide the kinds of information required. Thus far virtually all the systems considered had as their objective the furnishing of information about the range of objects up to distances of about 30 feet, within a cone of a few degrees.

Choice of Techniques

A number of methods of attack were initiated simultaneously, using radio, supersonic, and photoelectric techniques. A photoelectric method has yielded the most promising results thus far, and the remainder of this article will be devoted to a description of a system whose first embodiment is now suitable for practical evaluation, and is undergoing test by blinded veteran personnel under technical supervision. This unit weighs nine pounds, and is the size of a large book. It is intended to be carried in the hand at the operator's side for convenience of aiming. Fundamentally, the device is a one-point-at-a-time, short-range range finder with a small earphone by means of which the user receives coded information about what the device sees.

Optical Triangulation Principle

The principle of operation may be understood by reference to Fig. 1. An incandescent tungsten lamp at the focus of a lens L_1 causes a narrow beam of light to be projected along the axis of the system (an image of the source being formed at infinity). If the beam is intercepted, the illuminated spot on the object serves as a secondary source which is imaged in the plane of lens L_2, and then illuminates the phototube. If the axes of lenses L_1 and L_2 are parallel, the locus

vertical dimension. Thus two parallel traces, each 20,000 (or 15,000) microseconds long, are formed with pedestals, markers and received signals superimposed on them. The pedestals are formed by the output triggers of the A and B selectors, and the time difference between the pedestals is determined by the settings of the coarse and fine delay controls in the selectors.

Operation as a Master

In the case of master station operation, the A pedestal is placed at a convenient position to the left of the top trace, and the B pedestal to the right on the lower trace by an amount equal to the slave station delay (usually 950 or 1,000 microseconds) plus twice the time of traverse between master and slave stations. Since the same trigger forms the A pedestal and the local (master) pulse, the master pulse appears at the beginning of the master pedestal. When the remote slave station is maintaining proper sync, the slave pulse appears at the beginning of the slave pedestal. Adjustment of the continuous delay in the B selector permits placing the two pulses directly one under the other on the expanded (fast) sweep. The operator of the master station is thus enabled to monitor the synchronization performed by the slave station and to give warning if the synchronization fails. In this way, two checks are provided on the synchronization (in addition to monitor stations set up for the purpose).

Operation as a Slave

When the timer is used in a slave station, the two-way links are connected in the B positions, and the local (slave) transmitter is triggered by the B selector, so the slave pulse must appear at the beginning of the slave pedestal. The remote master pulse appears to the left on the master pedestal by an amount determined by the settings of the A selector. This amount is set at a particular value (950 or 1,000 microseconds), known as the slave station delay. Provision is made for changing this delay in accordance with a prearranged code, for use in wartime to confuse the enemy should he attempt to use the transmissions.

The slave station operator views

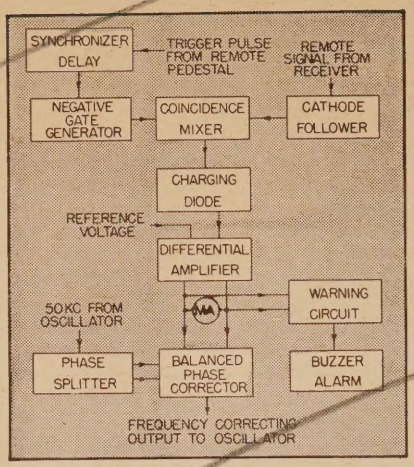


FIG. 9—Block diagram of the automatic synchronizer which keeps slave and master pulses in step without manual control

master and slave pulses on the fast sweep and adjusts the oscillator phase shifter as required to keep the two pulses superimposed. In this manner the slave station is triggered in rigid synchronization with the reception of the remote master pulses.

Automatic synchronization

A device which performs slave station synchronization automatically has been introduced to relieve the burden of manual operation of the slave timer. This device, known as the synchronizer, is used normally only for type B operation. The block diagram of the synchronizer is shown in Fig. 9. The synchronizer compares the time of occurence of the remote (master) signal with that of the remote (A) pedestal in the timer. The comparison is carried out in a so-called coincidence mixer, an amplifier fed from two sources. To the control grid of this amplifier the remote signal is fed directly from the receiver. The cathode of the same tube receives a narrow rectangular wave, about 5 microseconds long, which is derived from the A selector of the timer. The pulse which forms the A pedestal in the timer is passed through a synchronizer delay multivibrator which introduces a delay equal to the cumulative delay experienced by the local signal. The delay pulse generates the gate pulse.

Coincidence Mixer

The coincidence mixer with remote signal and gate applied to grid and cathode respectively, passes plate current only when both signals are present simultaneously, and the magnitude of the current passed depend on the time relationship betwee them, increasing as the gate mo nearly approaches the center of th remote pulse.

Differential Amplifier and Alarm

The output of the coincidenc mixer thus consists of pulses, th peak value of which depends on th degree of coincidence between re mote signal and the pedestal o which it is displayed. These pulse are passed through a diode detecto and charge a capacitor to the pea value of the pulses. The voltag across the capacitor is thus a meas ure of the degree of synchronization The capacitor voltage is compare with a steady reference voltage in differential amplifier which develop an output proportional to the differ ence between them. If this differenc voltage exceeds a certain limit i actuates a relay and a warning buzzer operates, indicating depart ure from the established limits o synchronization (plus or minus one microsecond).

Time-Frequency Corrector

Variation in the difference voltage actuates a balanced phase corrector, consisting of two tubes fed voltage from the 50-kc oscillator in the timer. The latter voltage is split into two phases, 180 degrees apart, which are fed to the control grids of the phase corrector tubes. The screen grids of the same tubes receive the difference voltage from the differential amplifier. Consequently the voltage appearing across the common plate connection of the two tubes and ground, shifts in phase as the difference voltage varies. This 50-kc signal, with phase shifting in accordance with the relative displacement of the remote signal and the gate signal, is fed back to the 50-kc oscillator in such polarity that it "pulls" the oscillator frequency in the proper direction to overcome the departure from synchronization.

Readers interested in more complete descriptions of Loran equipment will be interested to know that the Radiation Laboratory is preparing a book on the Loran System which will be issued as one of the 28 volumes in the Radiation Laboratory Technical Series, to be published in 1946.—D.G.F.

AID For The BLIND

An experimental photoelectric ranging device gives aural indication of the angle between a projected beam of light and the reflected beam from an obstacle. The angle depends upon distance to the object, which can be interpreted from a coded tone signal by the operator

of image-points corresponding to the range of object-points from infinity to some near point, *P*, will be along a line *Q-Q'*. For practical purposes this line may be satisfactorily approximated by a straight line nearly perpendicular to the axis of the receiver lens. The problem of ranging, then, is one of determining the position of the received image along the line *Q-Q'*.

The scheme adopted for accomplishing this is mechanically to interrupt the rays reflected from the object before these rays are received by the phototube. For the purpose of this interruption, a flat cone-shaped code disc of perforated metal, or a film of varying density, is rotated at a constant rate in front of the cell. The generatrix of the cone-shaped disc coincides with *Q-Q'*, and the cone is mounted with its axis parallel to the receiver lens. The signals created by the cell due to these interruptions form a code understandable to the trained operator of the device, and are transmitted to him by means of an earphone. By these means a wide variety of codes is possible. For purposes of illustration, Fig. 2A shows one which gives dot-dash signals, and Fig. 2B shows one which depends upon a rate of interruption. Thus, in the first case, the rays from a near object causes three closely spaced signals followed by a long pause for each revolution of the disc. As the object recedes, the image overlaps the next code signal, which is a dot and a dash, and the signal is three dots and a dot-dash. The relative amplitude of the two signals would depend upon whether the range corresponded more closely to the three dots or the dot-dash. With further increase in distance of the object, the signal would become just dot-dash, and so on.

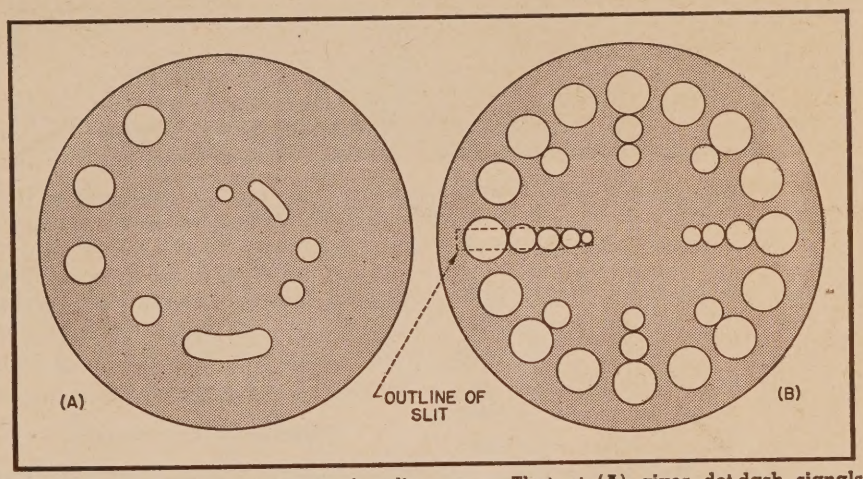


FIG. 2—Two experimental types of coding cone. That at (A) gives dot-dash signals, while that at (B) gives a low-frequency tone whose pitch depends upon distance to an obstruction

In the arrangement shown by Fig. 2B, the received rays would be interrupted at rates which increase in geometric steps as one progresses from the center of the cone to the edge (corresponding to large and small distances, respectively). When the image overlaps two rates, the higher rate will be effective, with alternate interruptions accented. In all cases the coding apertures increase in size with decreasing distance because of the increase in image size as the distance decreases.

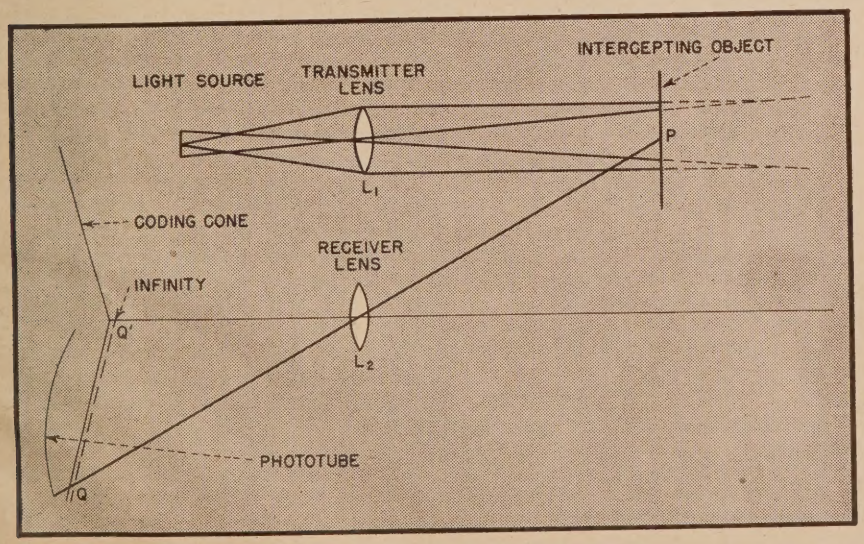


FIG. 1—Schematic diagram illustrating triangulation ranging principle. As the distance to the intercepting object becomes great, the reflected beam passes nearly straight through the axis of the receiver lens. A series of holes in the coding cone allows interpretation of the angle of intercepted light on the photocell

Modulated Light Source

It is apparent that to distinguish the projected light from the ambient, it is necessary to modulate the former in some way. This is accom-

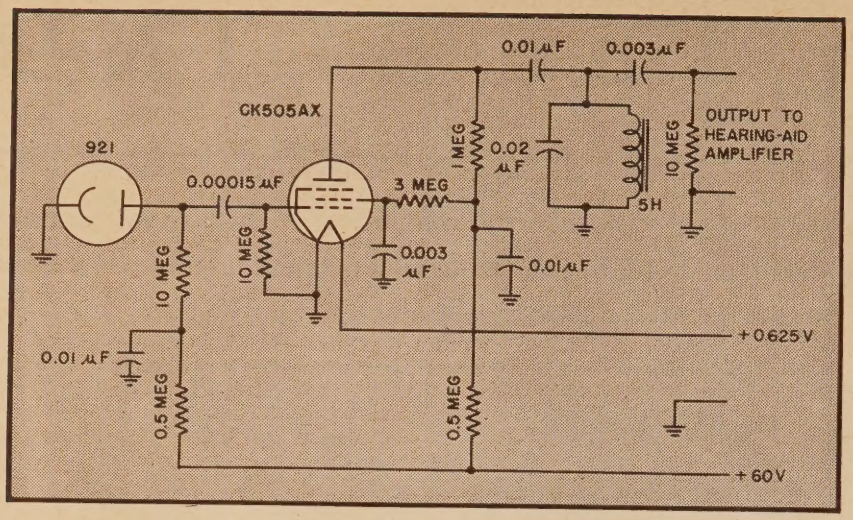


FIG. 3—Schematic wiring diagram of the phototube stage and the first stage of the amplifier. The output is fed into a slightly modified, conventional hearing-aid unit

plished by mechanically interrupting the light output of the transmitter by means of a rotating perforated disc, at the rate of 500 cps. The motor used to drive this disc is also used to drive the coding cone through a train of speed-reducing gears.

The received intelligence-bearing signal thus consists of 500-cps modulated light coded with dots or other characteristic indications. This is detected by a conventional photoemissive gas-filled phototube, and by an amplifier tuned to 500 cps. Presentation of the information is aural, using a standard air-conduction type hearing-aid receiver.

Design Considerations

In formulating a practical design, the principal considerations involved are the geometry of a device which will provide suitable minimum range and range increments, and the signal-noise ratio considerations, which determine such things as the maximum range and the weight of the power supply. With the arrangement provided in the first model of the device, using standard components, the minimum range is three feet. The specifications of transmitter and receiver optical systems follow. Transmitter lens: focal length, 1.5 in.; diameter, 1.0 in.; achromat. Receiver lens: focal length, 3 in.; diameter, 2.0 in.; achromat. Separation of axes: 5 in.

The light source is a 3-watt flashlight lamp with prefocused base. With this arrangement the distances corresponding to those for which the received images just fail to overlap are 3.5, 5, 7, 10, and 20 feet. Thus, pure signals would be produced from obstacle at these distances.

Signal-noise Calculations

The signal-noise ratio provided by the system may be calculated for the general case, if we assume a conventional emission-type phototube, and if we assume that in bright sunlight shot-noise due to steady background light illuminating the phototube is the limiting noise.

Thus, for an object at infinity

$$\frac{e_S}{e_N} = \frac{S_S W P_S D_R}{4d^2 \sin\theta} \sqrt{\frac{1}{e \Delta S_B B}} \times \left(1 - \frac{1}{\sqrt{1 + (1/4f^2)}}\right) \quad (1)$$

where e_S = rms signal voltage
e_N = rms shot-noise voltage
S_S = phototube light-to-current conversion factor for signal
W = candle power of source
D_R = diameter of receiver lens
ρ_S = reflectance of object for transmitted light
ρ_B = reflectance of object for background light
d = distance of object
θ = semi-angle of acceptance of receiver of objects at infinity
e = electron charge
Δ = amplifier bandwidth
S_B = Phototube light-to-current conversion factor for background
B = background brightness
f = f-value of transmitter lens

In deriving the above it has been assumed that optical losses are negligible, the projected light is chopped sinusoidally with no loss, and the obstacle intercepts the whole beam.

The values of the various parameters for the model are approximately as follows: f, 1.5; θ, 0.75 deg; W, 3 candles; Δ, 100 cps; D_R, 2 in.; S_S, 150 x 10^{-6} amp per lumen.

Assuming $S_S = S_B$, and $d = 30$ feet, we have

$$\frac{e_S}{e_N} = 2\,\rho_S/\sqrt{B} \times 10^3 \quad (2)$$

From the definition of the various photometric quantities we have

$$B = I\,\rho_B/\pi \quad (3)$$

where I is the ambient illumination. Combining Eq. 2 and 3 and assuming $\rho_S = \rho_B = \rho$ gives

$$e_S/e_N = 2\sqrt{\pi\rho/I} \times 10^3 \quad (4)$$

For temperate latitudes at noon, I = 10,000 foot-candles, giving

$$e_S/e_N = 35\sqrt{\rho} \quad (5)$$

A system with the design parameters given should then be capable of providing an intelligible signal over a reasonably wide variety of conditions of distance, ambient illumination, and reflectivity.

Interference from External Light Sources

In the foregoing only fundamental statistical noise has been considered. There are in addition extraneous light signals which may be picked up that mar intelligibility, most important among these being 120-cps signals due to artificial light sources, and noise due to modulation of ambient light by the coding cone.

Both of these may be dealt with satisfactorily by choosing a sufficiently high modulating frequency for the transmitter and tuning the receiver amplifier sharply about that frequency, with special attention to keeping the low-frequency gain as small as possible. Despite these measures, 120-cps signals are audible if a source of a-c light is imaged on the coding cone. But this is relatively improbable chance, and in any case provides useful information. Signals of this frequency due to indirect illumination are effectively filtered out, however.

The coding has been designed so that signals generated by the coding cone shall have a minimum of high-frequency components. In the present model this is accomplished by having the minimum number of code symbols at relatively slow speed of rotation (1 to 2 per second), and by shaping the cone apertures so that there are no abrupt changes in phototube illumination as the disc rotates. Low-frequency noises, audible as "plop-plop", due to modulation of

ght from backgrounds of high ightness by the coding cone, can be ard from the sky under certain con- tions. It should be possible to re- ice or eliminate these by more fective low-frequency filtering, or placing the receiver above the ansmitter, so that the former will most always be illuminated by ints below the horizon.

To keep the d-c illumination on the hototube to a minimum, the coding ne is backed by a slit which lies ong the line Q-Q'. To provide the aximum signal, the width of the it should be the same as the diam- er of the received image. This ould make it closely a triangle, hose vertex corresponded to infin- y. However, troublesome modula- on of ambient light is due primar- y to the code signals corresponding the closer range, because of the rge size of the corresponding aper- ures. Since signals at the close ranges are usually of more than ade- quate amplitude, the slit has, in fact, been made of constant width for about half its length, as shown in Fig. 2B.

Circuit Characteristics

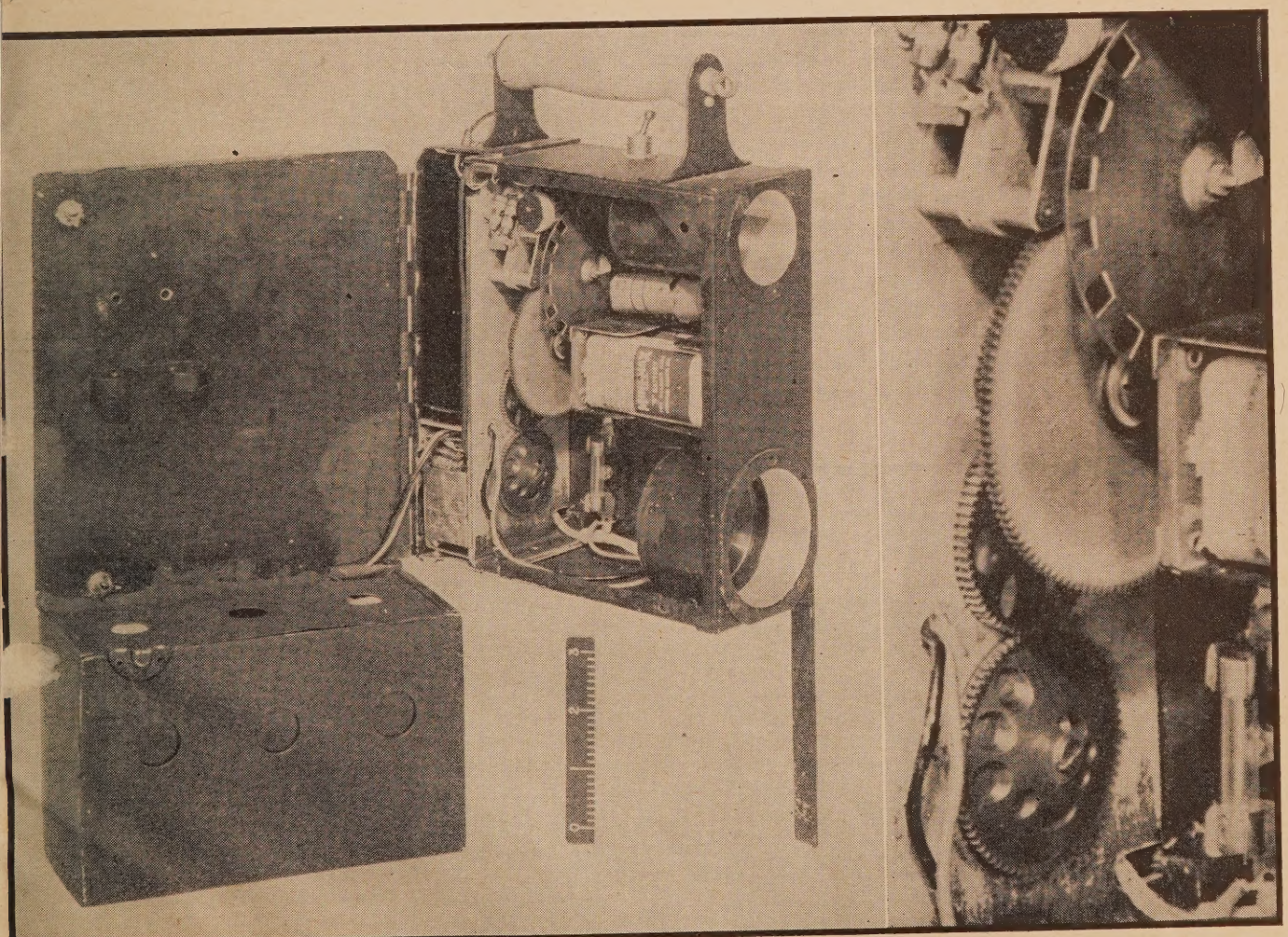
The amplifier in the first model consists of four stages in cascade, with an overall voltage gain of 95 db. Hearing-aid tubes and components are used throughout. The schematic wiring diagram of the phototube and first amplifier stage is given in Fig. 3. Most of the frequency discrimination is provided by the tuned circuit in the plate of the first stage to prevent early overloading by low-frequency ambient signals. The inductor used has a Q of approximately 9 at 500 cps. This part of the circuit alone provides a 6-db drop in gain at approximately 50 cps plus or minus the frequency of maximum gain. The remainder of the amplifier is a commercial hearing-aid unit modified to peak at 500 cps. It uses RC filtering only, and provides relatively little useful frequency discrimination except at the lowest frequencies.

Mechanical Problems

Close attention must be paid in design of the electronic parts to minimize mechanical, electrical, and magnetic coupling between them and the motor. A motor having good speed stability is also essential if maximum advantage is to be obtained from the narrow band width of the receiver. A completely satisfactory motor has not yet been obtained.

Acknowledgments

Invaluable assistance in the design and construction of the first test model has been provided by Messrs. N. L. Heikes, E. Blutman, A. Gray, and E. Wiler of the Signal Corps Engineering Laboratories.



Interior view of the sensory aid. The battery which runs the driving motor is contained in the compartment at the lower left. The enlarged detail to the right shows the gear train driving the coding cone (lowest toothed wheel) and the 500-cps chopper modulator (at top with square apertures)

R-F Soldering of

R-f soldering of feed-through insulators to back of meter case

R-f soldering of pole faces to Alnico magnets of meter movements

THE PRODUCTION of solder-sealed meters capable of withstanding 25-inch vacuum tests involves a number of critical soldering operations. The edge-metallized glass window and the glass-insulated feed-through terminals must be uniformly and cleanly soldered to the steel case of the instrument, with no pinholes or flux inclusions. Ordinary techniques involving soldering irons or torches did not heat the entire required area at a uniform rate, left a rough, unfinished appearance, and required a long time-cycle for each operation.

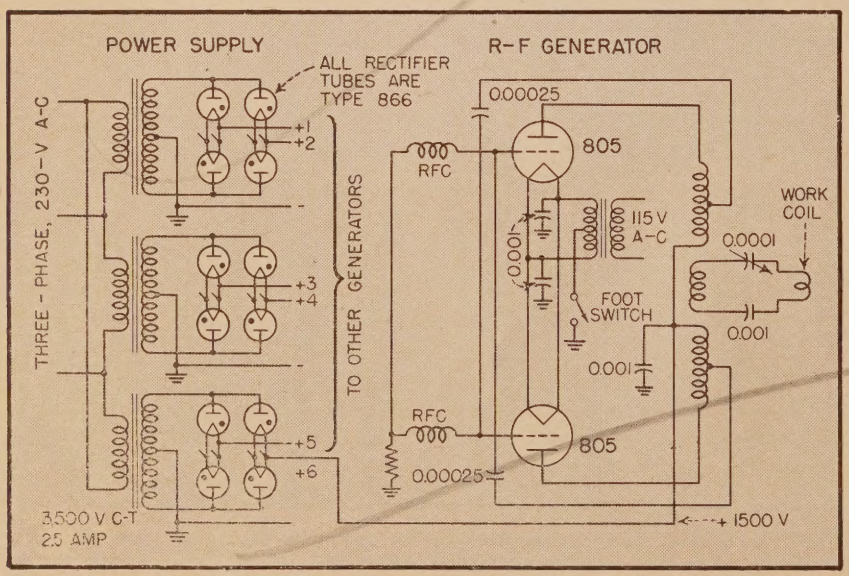
Bearing in mind that a number of stations or fixtures were required to handle the different operations, and considering the safety factors involved, it was decided to build a number of low-power r-f generators that could be plugged into high-voltage d-c outlets scattered throughout the plant and fed from a master d-c power supply.

Placing the power equipment in a remote section of the plant, on a shelf near the ceiling where a ladder was required for access, minimized the danger of accidents to personnel operating the units and prevented unauthorized persons from tampering with the power supply.

Design of R-F Generators

The r-f generators were mounted on the benches in standard table rack cabinets, with a heavy cable running from each to a foot switch that is mounted on the floor and used to turn the generator on and off. The foot switch is connected in the filament center-tap lead of the generator and provides effective keying, as the plates are continually energized.

The generator itself is a simple push-pull oscillator using type 805 tubes operated somewhat below their maximum rating to insure stability. In most applications the generator is



Circuit of remotely located 1,500-volt d-c power supply and one of the r-f generators used at bench locations. No filtering is required in the power pack, which has six independent output lines. Generators having small loads may be paralleled on one line, so that the power pack can handle ten or more units simultaneously under some operating conditions. Automatic timers prevent closing of power pack plate circuits until the rectifier filaments are heated

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